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A Fundamental Parametric Study on the Solidification of Malaysian Dredged Marine Soils

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Abstract: An enormous amount of dredged soils was generated from Malaysian rivers, lakes and seas. These dredged soils have poor geotechnical properties and are generally classified as "useless materials" [1]. However dredged soils can be recycled and reused as a potentially useful geo-material by solidification. This paper presents the study exploring the reuse potential of Malaysian dredged marine soils via the solidification technique, i.e. by using ordinary Portland cement and Class F fly ash. The dredged sample was essentially a high plasticity clay with a natural moisture content of approximately 166 %. As determined from standard compaction tests, the maximum dry density and the optimum moisture content were 1.49 Mg/m^3 (equivalent to14.62 kN/m^3) and 24 % respectively. XRF (X-ray fluorescence) analysis showed that the material contained high concentrations of SiO_2 and Al_2O_3. This was supported by the XRD (X-ray diffractometry) results, showing presence of quartz, halite, calcite and kaolinite as the primary compounds in the sample. The dredged soil was solidified with 10 % of additives by dry mass of soil with various ratios of cement: fly ash, i.e. 10:0, 7:3, 5:5, 3:7 and 0:10. The specimens were then subjected to curing times of 3, 7 and 28 days. pH of the solidified specimens showed an increment with increased cement content as well as curing time. Observations with FESEM (Field Emission Scanning Electron Microscopy) revealed effective sealing of voids within the original soil mass through the solidification process, evidence of the formation of cementitious products. These cementitious gels, such as calcium silicate hydrate (CSH) and calcium aluminium silicate hydrate (CASH), would play a crucial role in strength development of the treated dredged soil. As a general conclusion, solidification using cement-fly ash could revive the otherwise discarded dredged marine soils for reuse as a sound geo-material in various civil engineering applications, especially as a backfill material.

Key words: Dredged marine soil · Solidification · Cement · Fly ash

INTRODUCTION

Dredging is not a new engineering technology since it has existed at least as far back as the Roman times [2]. The definition of dredging is the removal of material from the bottom of lakes, rivers, harbours and other water bodies. The dredging process includes loosening or dislodging the materials, disposing it to the open water and transporting it to the site where it is to be relocated and the relocation again [3]. Most dredging is carried out to maintain or deepen water depths for safe and efficient navigation of vessels. In Malaysia, the traditional handling of dredged materials is either discharge into a confined disposal facility (CDF) or designated open waters. Unfortunately offshore dumping could inadvertently lead to negative physical, chemical and biological impacts to the marine environment. Due to growing scientific knowledge and public awareness of nature conservation, dredged materials have recently been seen as a valuable resource for reuse, which could replace the traditional "dredged and disposed" approach. Some areas of applications include habitat creation/restoration, landscaping, road construction and land reclamation [4].

In year 2012, over 3.5 million m^3 of dredged materials were generated from the rehabilitation of the Lumut waters of Perak state in Malaysia, to maintain and enlarge the navigation channels for commercial, fishing and national defense purposes. The dredged materials were disposed offshore at a designated sea disposal site. While located at an adequate distance from disrupting the local fishermen's livelihood, such disposal method would still

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create disturbance to the aquatic ecosystem [5]. For instance, light attenuation by suspended sediments can affect the amount of light available to seagrass plants, coral reefs and other marine organisms [6]. Also, soft bottom macrobenthic assemblages may respond quickly to the disturbance associated with the dumping of dredged materials and affect the overall marine ecosystem [7]. Dredged materials may contain toxic chemicals too and contribute to adverse effects on marine organisms at the disposal area and surrounding waters.

It is therefore imperative that a more sustainable solution is designed to address the risks incurred by offshore disposal of dredged marine soils. One potential solution is the recycling and reuse of the mud-like material. Nonetheless some enhancement process is necessary to transform its poor qualities to acceptable levels befitting good geo-materials for civil engineering applications. The process examined in this study is the solidification method, which involves mixing the soil with some hydraulic binders to improve the physical and mechanical properties. The treatment would improve the soil's strength and reduce its vulnerability to water; and if the treated soil is able to withstand traffic loading under all weather conditions without deformation, then it is consider as stable [8].

MATERIALS AND METHODS

Dredged Marine Soil: The soil samples were collected at a depth of 8-12 m below the sea water level by using a trailing suction hopper dredger (TSHD). Grab samples of dredged marine soil were then taken from the storage tank of the dredger manually. Placed in double-layer of plastic sampling bags, the dredged soil was next transported to the laboratory and stored in a pair of covered containers at average room temperature of 20°C. To prepare representative samples of the material prior to forming soil-binder mixtures, half of the required quantity of the soil was scooped from each container and hand-mixed in a separate smaller container. It was then left overnight to ensure uniform redistribution of the pore water, before adding predetermined amounts of cement and/or fly ash for solidification. The mixing was conducted using a conventional kitchen mixer to form a uniform paste of the mixture.

Cement: Cement is arguably the most popular binder's choice. By first classifying the soil sample according to the AASHTO (American Association of State Highway and Transportation Official) [9] guidelines, the cement dosage required for effective solidification can be estimated using Table 1. Note that the cement quantities were proportioned on a weight basis in terms of the percentage of the oven-dried soil. It is cautioned that these cement contents are only estimations and must be verified by the ASTM (American Society for Testing and Materials) [10] durability test. Indeed, Dallas and Nair [11] pointed out that many soils can be successfully treated and improved with considerably lower cement contents, some examples of which are illustrated in the findings of Chan [12] and Mokhtar and Chan [13].

Fly Ash: Fly ash is a byproduct of coal combustion for power generation. Fly ash is produced from the combustion of coal and is collected by electrostatic precipitators. This results in the ash particles being spherical and non-uniform in size (Figure 1). Two major classes of fly ashes are mentioned in ASTM C618 [14] based on their chemical compositions resulting from the type of coal burned, namely Class F and Class C ashes. Class F ash (as used in the present study) is produced from burning anthracite or bituminous coal, while Class C ash is produced from the burning of sub-bituminous coal and lignite. The latter usually has cementitious properties in addition to pozzolanic properties due to its free lime content, unlike the former which is rarely cementitious when mixed with water alone [15]. Class C fly ash can be used on its own to solidify moderately plastic soils due to the presence of 20-35 % calcium compounds (CaO), making it self-cementing when mixed with water without activators, like lime and Portland cement [16]. As reported by the same author, fly ash treatment can also reduce the swell potential for fat clays and increase the strength of pavement subgrades. In coarser aggregates, fly ash functions both as a pozzolan and/or filler to reduce the void spaces among the aggregate particles.

Test Methods

Natural Moisture Content: This involves the determination of the moisture content of a specimen of soil as a percentage of its dry mass. Moisture content is useful in the classification of natural soils. The oven drying method is the definitive method for this purpose [25]. The sample is oven-dried at 105°C for 24 hours to remove the entrapped moisture. For each mixture in this study, the measurement was carried out on 10 samples to ensure better accuracy in the data obtained [25].

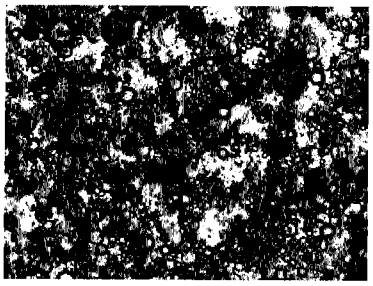

Fig. 1: 20x magnification of the fly ash (using the CANON Eclipse T100 inverted microscope)

Liquid Limit Test: Referring to [25], the fall cone method for determining liquid limit is directly related to the static shear strength of the soil. Water is added by small increments to soften the soil to the point of allowing cone penetration in the range of 15-25mm. The liquid limit is defined as the water content of the sample at which the penetration is 20 mm, i.e. the lowest moisture content at which the soil is liquid.

Plastic Limit Test: In determining the plastic limit based on [25], the sample is gently rolled into threads of approximately 3 mm diameter until crumbling is observed. The first crumbling point is taken as the plastic limit, i.e. the lowest moisture content at which the soil is plastic.

Wet Sieving: If a soil contains high proportions of silts or clay, or both, it is necessary to conduct wet sieving [25]. This is the only practicable method to completely separate the fines in order to measure the proportion of fine materials [17]. It is necessary to first immerse the sample in a dispersing agent to separate the aggregates to discrete particles of soil. The sample is next washed over stacked sieves of 3.35 mm, 2 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm and 63 μm. The retained portion is air dried and the weight is measured.

Hydrometer Analysis: The hydrometer is a floating device used to determine the percentage of fine sand, silt, clay and inorganic fraction of soils. This test is not usually conducted if the passing percentage on 63 μm sieve is less than 10 %. The sample is pretreated with a dispersing agent (e.g. sodium hexametaphosphate + sodium carbonate) and washed on the 63 μm sieve. This method is easily conducted and it can provide an accurate result for most engineering purposes [25].

Particle Density Test: This test is to determine the average particle density for particles which are finer than 2 mm. The term particle density is used to replace the previously used term of "specific gravity" to comply with international usage. Distilled water is normally used as the density bottle fluid, but if the soil contains soluble salts, kerosene should be used. The density of the liquid should be measured separately [25].

Loss on Ignition (LOI) Analysis: LOI refers to the mass loss of a combustion residue whenever it is heated to high temperatures in an air or oxygen atmosphere. The mass lost from a soil on ignition is related to the organic content of the soil sample. However, in some soils, the mass loss can be due to the loss of moisture, carbon, sulfur or other elements, from the decomposition or combustion of the residue. In this test, the sample is oven-dried at 105°C overnight, followed by 3 hours of firing at 440°C in a furnace.

pH Test: The sample is first oven-dried at 50°C for 24 hours and sieved on a 6.3 mm sieve. 30 g of the sample in dry form is next added with 30 g of distilled water. Since the samples were limited, the dry weight of each sample was reduced to 10 g in this study. The volume of distilled water added to the sample was 10 ml to attain the soil:water ratio of 1:1. The mixture is cured overnight at room temperature before the pH reading is taken.

Compaction Test: This test is suitable for soils containing particles less than 20 mm. In general, clay soils and well-graded sandy or silty soils show a clearly defined peak to the compaction curve. A zero air void line is plotted for the ease of comparison by adjusting the curves to the same particle density, if more than one soil sample is being examined [17].

X-Ray Fluorescence (XRF) Analysis: The X-ray fluorescence (XRF) spectrometer is a non-destructive method for the chemical analysis of rocks, minerals and sediments. It is typically used for bulk analysis of large fractions of geological materials. The fundamental principles of this instrumental method involve the interactions between X-rays and electron beam.

X-Ray Diffractometry (XRD) Analysis: X-Ray diffractometry (XRD) is used for the characterization of unknown crystalline materials. It is widely used for the identification of fine grained materials (e.g. silt and clay) in geotechnical and geo-environmental engineering.

Table 1: Cement requirement for AASHTO soil Groups

AASHTO Soil Group	Usual range (percent by volume)	Cement requirement (percent by weight)	Estimated cement content (percent by weight)
A-1-a	5-7	3-5	5
A-1-b	7-9	5-8	6
A-2	7-10	5-9	7
A-3	8-12	7-11	9
A-4	8-12	7-12	10
A-5	8-12	8-13	10
A-6	10-14	9-15	12
A-7	10-14	10-16	13

Table 2: List of test specimens

Specimen	Cement (%)	Fly ash (%)	Total binder, by dry weight of soil (%)
10C	10	0	10
10FA	0	10	10
5C5FA	5	5	10
7C3FA	7	3	10
3C7FA	3	7	10

Field Emission Scanning Electron Microscopy (FESEM): The equipment used for this analysis is the JEOL JSM-7600F model. FESEM is used for imaging the nanostructures of a variety of samples at very high resolutions. Since the dredged soil is a non-conductive sample, it was coated with gold to enhance the conductivity before being placed in the FESEM machine for analysis. The magnification factors used were 5,000, 20,000 and 40,000.

Binder Dosages: Referring to Table 1, since this soil falls under the soil group of A-7, 10-16 % of cement in dry weight should be added for effective solidification. For economic reasons and past recommendations for small binder dosages, e.g. Dallas and Nair [11], Chan [12] and Mokhtar and Chan [13], 10 % of the binder, i.e. cement and/or fly as, was added to the soil in this study. The specimens were left to cure over a period of 3 to 28 days for examination of the time effect on the changed properties. Table 2 gives a summary of the test specimens examined in this study.

RESULTS AND DISCUSSIONS

Natural Moisture Content: The average moisture content of the dredged soil was 166.2 %. A soil with natural moisture content higher than its liquid limit is considered very soft and may have very low shear strength, i.e. undrained shear strength of no more than 50 kPa [18]. As the dredged sample's liquid limit is 95.8 % (see *4.2*), it falls under this category of soft, weak material, requiring treatment before any beneficial reuse in engineering applications.

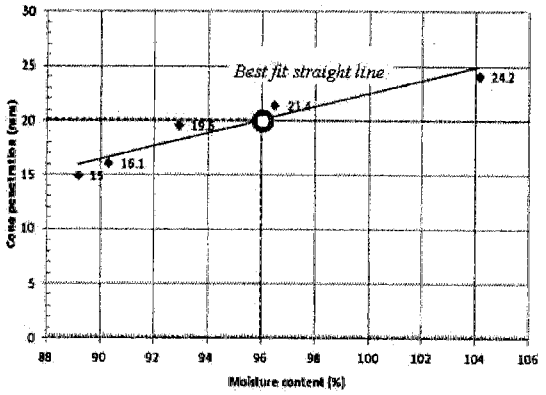

Fig. 2: Cone penetration versus moisture content

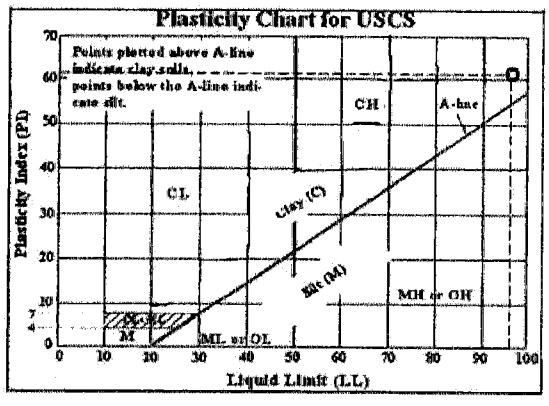

Fig. 3: Plasticity chart for the classification of fine-grained soils

Atterberg Limits: For determining the liquid limit (LL), cone penetration is plotted against moisture content in Figure 2. Corresponding to the cone penetration of 20 mm

is the liquid limit, i.e. 95.8 %. The average value of plastic limit (PL) is 34.4 %. The difference between LL and PL gives the plasticity index (PI), which in this case is 61.4 %. PI indicates the magnitude of the range of moisture content over which the soil remains plastic, where the inherent chemistry of the clay minerals binds the soil particles together. Referring to the Unified Soils Classification System's plasticity chart (Figure 3), the soil is classified as 'high plasticity clay' (CH).

Particle Size Analysis: The particle size distribution curve in Figure 4 shows that the passing percentage of gravel, sand, silt and clay are 3, 14, 8 and 75 % respectively, indicating the dominance of fine-grained materials in the soil. The ASSHTO classification system puts the soil under the category of 'clayey soil', or soil group of A-7-5. The group index (GI) of this soil is calculated to be 58, a parameter needed to evaluate the quality of soil as a highway subgrade material using the ASSHTO system [19]. Soils with GI values nearer to 0 are considered as good soils, while those with GI values larger than 20 represent soils which are unsuitable subgrade materials. As with the present dredged soil sample with GI = 58, solidification is necessary for its reuse as a sound subgrade fill material.

Particle Density Analysis: The average particle density of the dredged soil sample is approximately to 2.60 Mg/m^3. Most sand, silt and clay have particle density ranges from 2.60-2.80 [20]. Apparently the dredged soil's particle density lies in the lower region of this common range, though many clay particles fall close to particle density of 2.65 Mg/m^3. The presence of large amounts of heavy minerals, such as magnetite, limonite and hematite can result in higher particle density values too.

Compaction Test: The compaction curve of the dredged soil shown in Figure 5 indicates the maximum dry density as 1.49 Mg/m^3 or 14.62 kN/m^3 and the optimum moisture content as 24 %. As air in the voids of the soil mass cannot be expelled totally by manual compaction alone, the peak of the curve coincides with approximately 6-7 % of air left in the compacted mass.

Loss on Ignition (LOI): The loss on ignition parameter for the sample was found to be 6.33 %, suggesting the presence of a small amount of organic matter in the dredged soil. Soil with organic content greater than 20 % is considered as organic soil in geotechnical engineering. In fact, the mechanical characteristics of soil will no longer apply if the organic content exceeds 20 % [21].

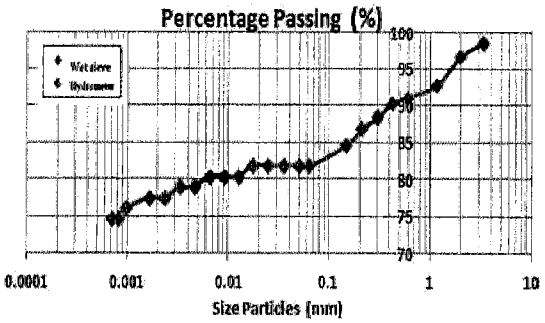

Fig. 4: Particle size distribution curve

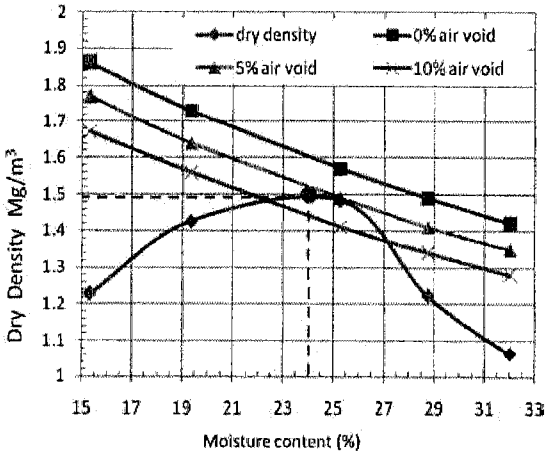

Fig. 5: Compaction curve of the dredged soil

According to ASTM C150, ordinary Portland cement should have an LOI value of less than 3 %. On the other hand, the LOI value for Class C and Class F fly ash should be less than 6 %, but the LOI value of Class F fly ash can be as high as 12 % [14]. The rather wide range provided is attributed to the variation in sources and properties of fly ashes.

Looking at Figure 6, all the solidified specimens follow a decreasing trend in LOI throughout the curing period up to a month, except for 3C7FA which shows a slight rise towards the end. As the constituents of the solidified specimens are relatively complex, i.e. soil, cement and fly ash and cementitious products from the chemical reactions, the LOI values barely represent the actual amount of organic matter present. In addition, it is very likely that the cementitous products coated and entrapped the organic matter contained in the respective raw materials, resulting in the weight loss measured in the LOI test as time progressed. Longer curing periods allow more hydration and pozzolanic reactions to take place, hence the less organic matter available or 'exposed' for combustion in the furnace.

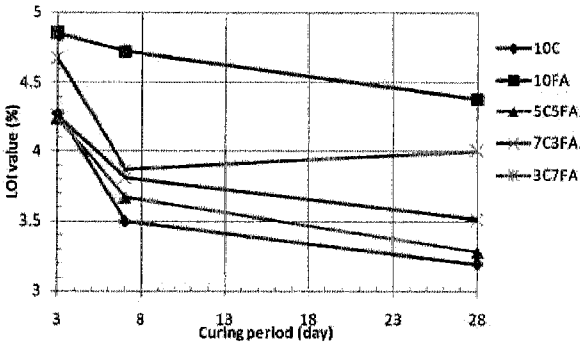

Fig. 6: LOI values at different curing times

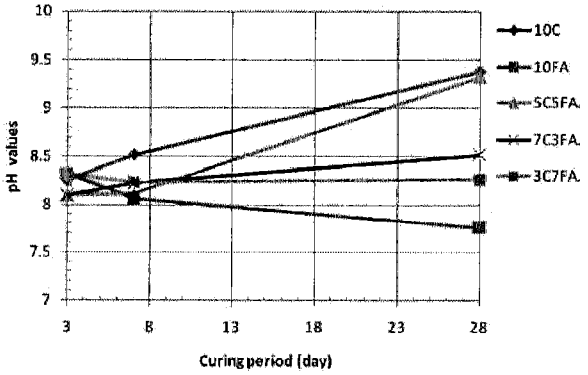

Fig. 7: pH readings at different curing times

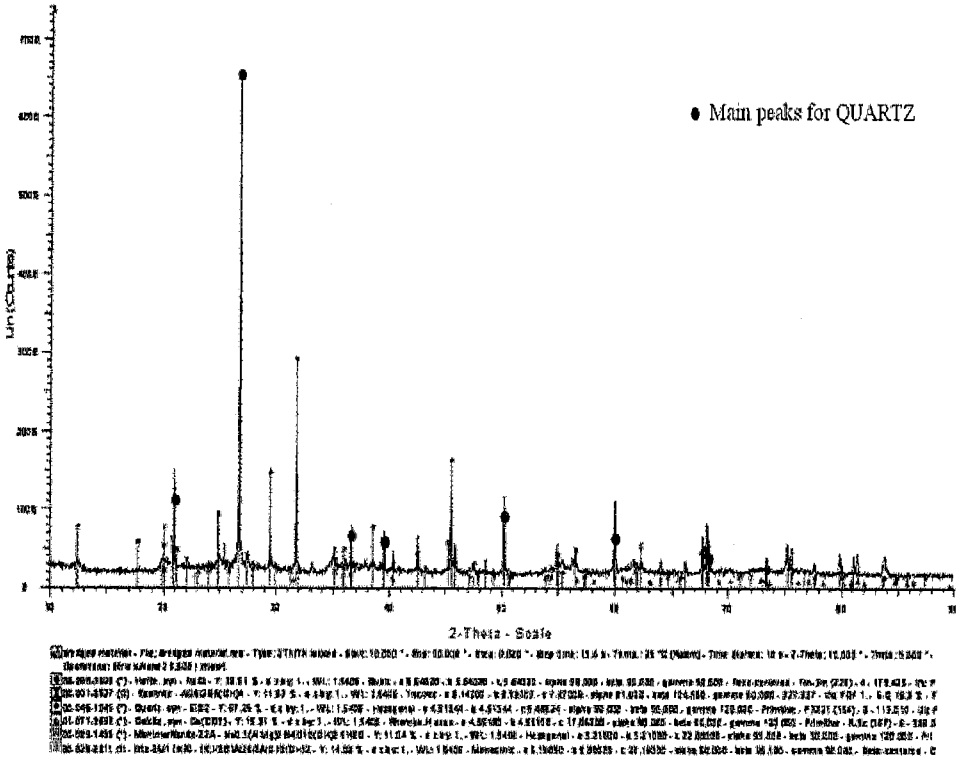

Fig. 8: XRD analysis of the dredged sample

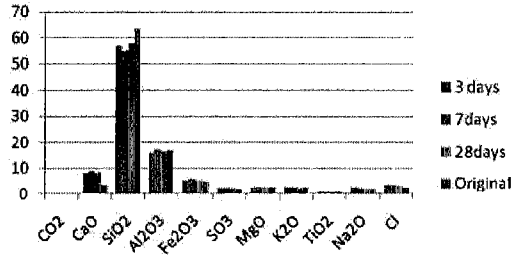

Fig. 9(a): XRF results of 10C at different curing times

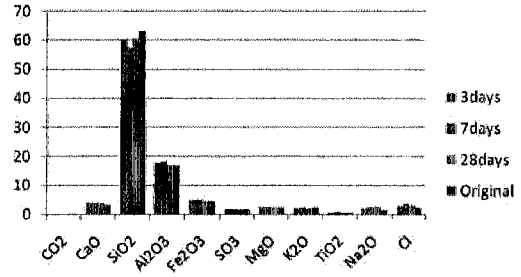

Fig. 9(b): XRF results of 10FA at different curing times

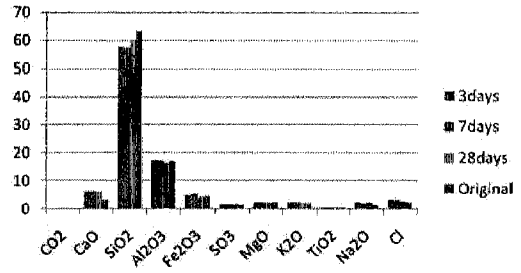

Fig. 9(c): XRF result of 7C3FA at different curing times

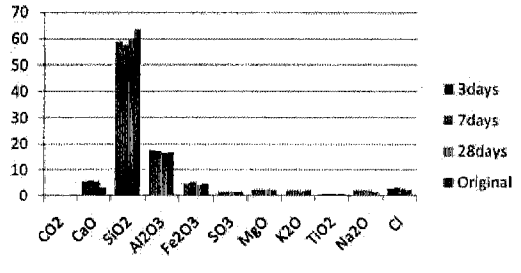

Fig. 9(d): XRF result of 5C5FA at different curing times

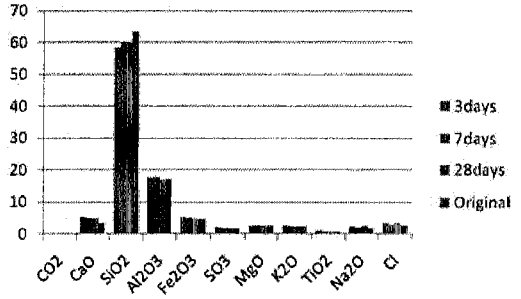

Fig. 9(e): XRF result of 3C7FA at different curing times

pH: The average pH of the natural dredged soil sample is 8.22, hence it can be classified as being moderately alkaline. Alkality is often associated with low organic content in the soil [21]. Figure 7 shows the pH values of the solidified specimens over the 1-month curing period. It appears that cement dosage of 3 % is the minimum before the pH trend starts to decline with time. Generally, the hydration of cement leads to pH increment of the pore water, caused by the dissociation of the hydrated cement [22].

As the soil is naturally alkaline (pH = 8.22), the addition of fly ash actually caused a reduction in the pH of the mixture, as demonstrated by the dip in specimen 10FA. According to Zhang *et al.* [23], the lower the pH is, the higher the degree of reaction in fly ash is in the mixture. This could explain the pH trend observed when fly ash content increased while the cement dosage decreased, where pozzolanic reaction of the fly ash caused the simultaneous occurrence of two mechanisms: (1) decline of the alkality of the pore water solution and (2) consumption of calcium hydroxide (CH) from the hydration of cement. The exception of 5C5FA and 7C3FA may be due to non-uniform mixing of the materials, leading to formation of sporadic and localized pockets of incomplete fly ash reaction within the specimens.

X-Ray Fluorescence (XRF) and X-Ray Diffractometry (XRD) Analyses: Silicon (Si) constitutes the largest share of element in the dredged soil, i.e. 63.3-63.5, followed by aluminium (Al) at 17.0-17.2 %. The high percentage of Si is attributed to the presence of quartz in dredged soil, as supported by the XRD analysis (Figure 8). It is not surprising to find abundant of quartz in geo-materials as it is the most common mineral in earth. Indeed, it is a significant mineral for all igneous, sedimentary and metamorphic rocks, which constitute the parent material of most soils.

For specimen 10C, as illustrated in Figure 9(a), a marked increase in the CaO content of the solidified specimen was recorded in comparison with the original soil (CaO = 3.33 %). On the other hand, the addition of FA alone (i.e. specimen 10FA) did not result in much change of the CaO content, as can be seen in Figure 9(b). This is understandable as the Class F fly ash itself contains negligible amount of CaO. This little amount of free CaO could cause dilution effect and reduce the quantity of cementitious gel formed. As a consequence, strength degradation could take place in the solidified soil.

Overall, judging from Figures 9(c)-(e), other elements in the mixture remained largely unchanged, regardless of the variations in the binder ratio and curing period.

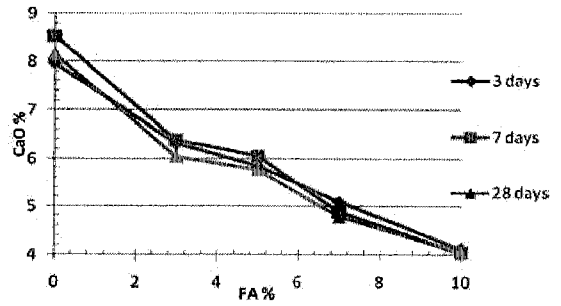

Fig. 10: The relationship between CaO and FA (fly ash) contents

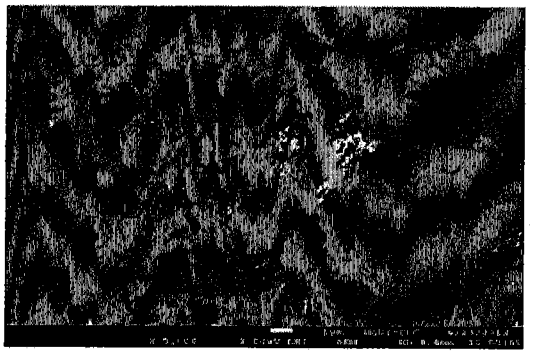

Fig. 11: FESEM image of the dredged soil under magnification factor of 5000

Fig. 12(a): Specimen 5C5FA, 3-day old

This is suggestive of the limited solidification impact of small dosages of binder in these soft dredged soils and that prolonged curing could not overcome the unsatisfactory solidification outcome from using small quantities of binder. Figure 10 shows the relationship between CaO content and fly ash dosage in the solidified specimens. Note the almost linear declining trend of the plot, irrespective of the curing period. This highlights the nominal effect of Class F fly ash in the solidification of the dredged soil.

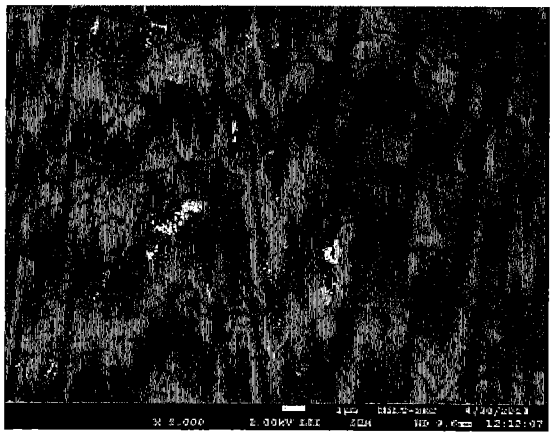

Fig. 12(b): Specimen 5C5FA, 28-day old

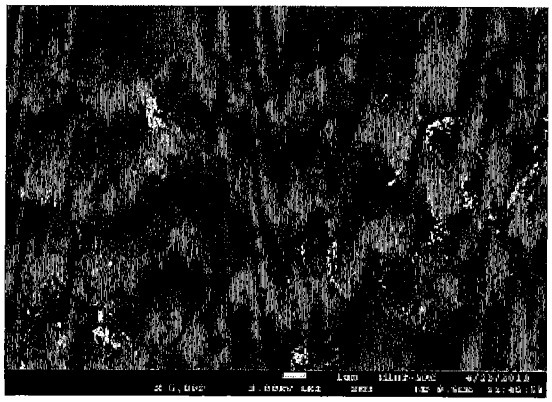

Fig. 13: Specimen 10C, 28-day old

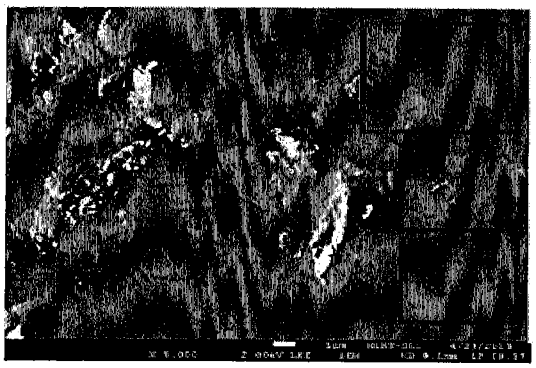

Fig. 14: Specimen 10FA, 28-day old

Field Emission Scanning Electron Microscopy (FESEM): The FESEM image in Figure 11 captures the original dredged soil as a poorly graded material with large pores. An unidentified object was found in the dredged soil (boxed in dashed lines), probably debris of foreign origin in the sample. Considering that the soil was collected from a near-shore seabed, exposure to influx of solid wastes from river discharge is not unlikely.

In Figures 12 (a)&(b), cementation was evident where the pores were significantly filled. Note that the particles size grew too as cementation bound the particles into larger aggregates, thus encroaching on the boundaries of the voids and eventually filling them. Cement treatment typically leads to flocculation of the fractions in soils, consequently increasing the particle size and modifying the plasticity of the original soil [24]. It can be seen that the soil's microstructure changed significantly with prolonged curing time, with the 28-day specimen in Figure 12b showing less voids and larger lumps of particles. Nonetheless the manifested changes in the geotechnical properties and textural composition due to cementation are affected by other factors too, such as the particle size, mineralogy, water content and chemical properties of the binder. The binder effect can be observed in Figures 13 and 14, which depict the 28-day old specimens of 10C and 10FA respectively. 10 % of cement apparently induced greater binding effect in the soil, producing larger aggregates and smaller pores (Figure 13), while 10 % of fly ash brought forth a lesser effect. This can be accounted for by the higher percentage of CaO in cement compared to fly ash (see Figures 9a and 9b), where CaO is the main compound for the cementitious reaction.

CONCLUSIONS

In an attempt to reuse dredged marine soils as an acceptable geo-material for civil engineering applications, a parametric study on the physico-chemical characteristics of a Malaysian dredged marine soil sample solidified with cement-fly ash was conducted. Following are the primary findings:

- The dredged soil has a natural water content in excess of its liquid limit ($w_{nat} \approx 1.75LL$), hence necessitating solidification to enhance the originally weak and characteristics for general handling and more importantly, load-bearing.
- The Atterberg limits indicate the dredged soil to be of the high plasticity clay type, susceptible to significant deformation under loading.
- Particle size analysis revealed the dominance of fines, making the dredged soil unsuitable as a subgrade fill material.
- The organic content of the dredged sample was found to be negligible, though solidification could effectively further reduce the amount via encapsulation within the cementitious gel formed.
- No marked change in pH was observed as the binder dosage was relatively small.
- Chemical composition of the soil remained largely unchanged and CaO emerged the main active compound for solidification to take place.
- Micro-imaging shows the solidification mechanism filling voids within the soil by cementation as well as enlarging soil aggregates.

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REFERENCES

1. Goldbeck, S., 2008. State of the Estuary Report, A Greener Shade of Blue.
2. Mountford, K., 2000. History of dredging reveals deeper need to understand Bay's bottom line. Bay Journal, 10(5): 8-10.
3. Riddell, 2003. "Dredging for development", International Association of Dredging Companies (IADC).
4. Pebbles. V. and S. Thorp, 2001. "Waste to Resource: Beneficial Use of Great Lakes Dredged Material", Great Lakes Commission.
5. Snyder, G.R., 1976. "Effect of Dredging on Aquatic Organisms With Special Application to Areas Adjacent to the Northeastern Pacific Ocean" A Marine Fisheries Review.
6. Bogers, P. and J. Gardner, 2004. Dredging near live coral. The 17th World Dredging Congress, Hamburg, Germany. WODCON XVII 2004, Paper A31; 2004.
7. Cruz-Motta, J.J. and J. Collins, 2004. Impacts of dredged material disposal on a tropical soft-bottom benthic assemblage. Mar Pollut Bull, 48(3-4): 270-80.
8. Flaherty, C.A., 2002. "The location, design, construction and maintenance of pavements". Edward Arnold Ltd.
9. AASHTO M-145-91, 2000. Classification of Soil and Soil-Aggregate Mixtures for Highway Construction Purposes.
10. ASTM, C150. Standard Specification for Portland Cement. American Society for Testing and Materials. West Conshohocken.
11. Dallas, N.L. and S. Nair, 2009. Recommended practice for stabilization of subgrade soils and base materials. National Cooperative Highway Research Program.

12. Chan, C.M., 2012. Variation of shear wave arrival time in unconfined soil specimens measured with bender elements. Journal of Geotechnical and Geological Engineering, 30(2): 419-430.
13. Mokhtar, M. and C.M. Chan, 2012. Settlement control of soft ground with cement-ricehusk stabilisation. Civil Engineering Dimension, Research Centre of Community Outreach, Universitas Kristen Petra, Indonesia, 14(2): 69-76.
14. ASTM C618-08a. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
15. Halstead, W.J., 1986. "Use of fly ash in concrete". Synthesis of Highway Practice 127, National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington DC.
16. Ferguson, G., 1993. Use of self cementing fly ashes as a soil stabilization agent. American Society of Civil Engineer.
17. Head, K.H., 1992. Manual of Soil Laboratory Testing. London, Pentech Press.
18. Chiu, C.F., W. Zhu and C.L. Zhang, 2008. Yielding and shear behaviour of cement-treated dredged materials. Eng Geol., 103: 1-12.
19. Das, B.M., 2010. Principles of Geotechnical Engineering. 7th ed. United State of America: Cengage Learning.
20. Huat, B.B.K., G.S. Sew and H.A. Faisal, 2004. Organic and Peat Soils Engineering. University Putra Malaysia Press, Malaysia. ISBN: 983-2871-08-5.
21. Maurer, I.S., D. Sauer, K.S. Ragnhild, Sperstad and Sørensen R. Revista Mexicana De Ciencias Geológicas, 2007. Soil formation in marine sediments and beach deposits of southern. Norway: investigations of soil chronosequences in the Oslofjord region.
22. Lee, S.T. and H.A. Faisal, 2004. Behaviour of Clayey Soils with Cement Additive. In The Proceedings of the 2004 Malaysian Geotechnical Conference.
23. Zhang, Y.M., W. Sun and H.D. Yan, 2000. Hydration of high-volume fly ash cement pastes.Cement and Concrete Composites, 22(6): 445-452.
24. Rekik, B. and M. Boutouil, 2009. Geotechnical Properties Of Dredged Marine Sediments Treated At High Water/Cement Ratio. Geo Marine Letters, 29: 171-179.
25. British Standard, 1377. 1990. Methods of test for soils for civil engineering purposes. Part 2: Classification tests. United Kingdom: British Standard Institution.